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The dynamic response of polymethyl methacrylate (PMMA) under explosive loading

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Abstract

Explosively-driven shock wave propagation, attenuation, and fracture growth were measured in polymethyl methacrylate (PMMA) samples of various geometries. The samples were loaded with RP-80 exploding bridge wire detonators. Free surface velocity was measured using Photon Doppler Velocimetry (PDV). High-speed schlieren imaging was used for determination of the shock velocity, and fracture growth rate.. The measured quantities describe the explosively driven shock state of PMMA

Motivation

The dynamic response of geologic materials under explosive loading is of interest for many applications. The fracture behavior of PMMA is similar to that of geologic materials [1] and due to its optical clarity is an ideal window material for shock studies [1-2]. Previous PMMA shock studies carried out through impact experiments [2-3] which do not accurately describe the shock behavior imparted by an explosive source.

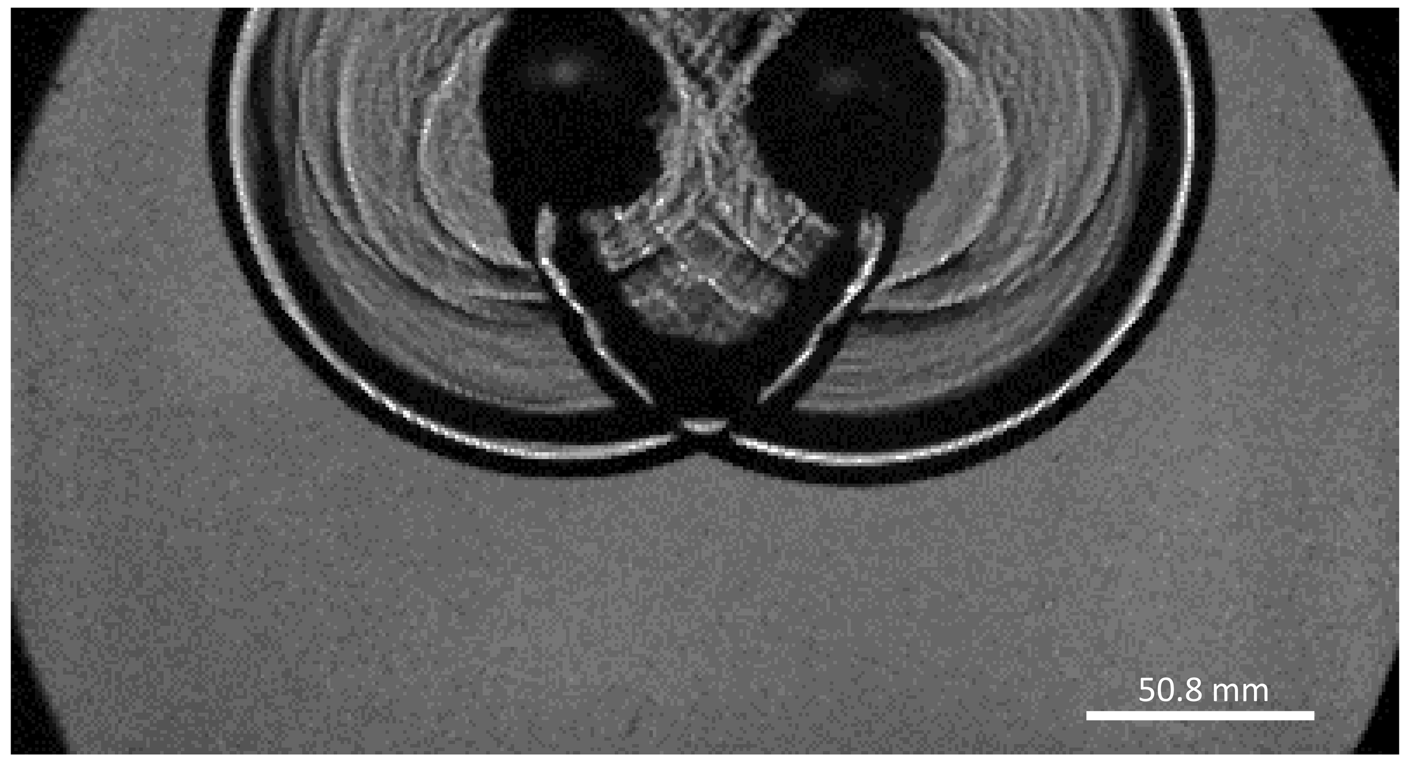

Fig 1: Image of a 0.3m x 0.3m x 0.3m PMMA sample with two explosive sources for understanding shock wave and fracture interaction.

Future work

The present work has developed measurements of the shock wave velocity, and fracture growth in explosively loaded PMMA samples the next steps will conduct small scale tests where the propagation distance is reduced to obtain data closer to the source. The fracture behavior will also be further investigated experimentally and theoretically. Fracture experiments will be conducted in disk-shaped PMMA samples. The fracture, and shock experimental results will be used to understand the shock state of the PMMA near the explosive source.

Acknowledgments

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High-speed Imaging of Shock and Fracture

Schlieren imaging (Fig. 2) is an imaging technique allowing for the visualization of changes in density, pressure, and temperature [4]. Two high speed cameras are used to visualize the event at 5 million frames per second (fps) and 30k fps to capture shock propagation and fracture growth, respectively. A spoiled coherent laser was implemented as the illumination source to reduce external illumination and pixel blur.

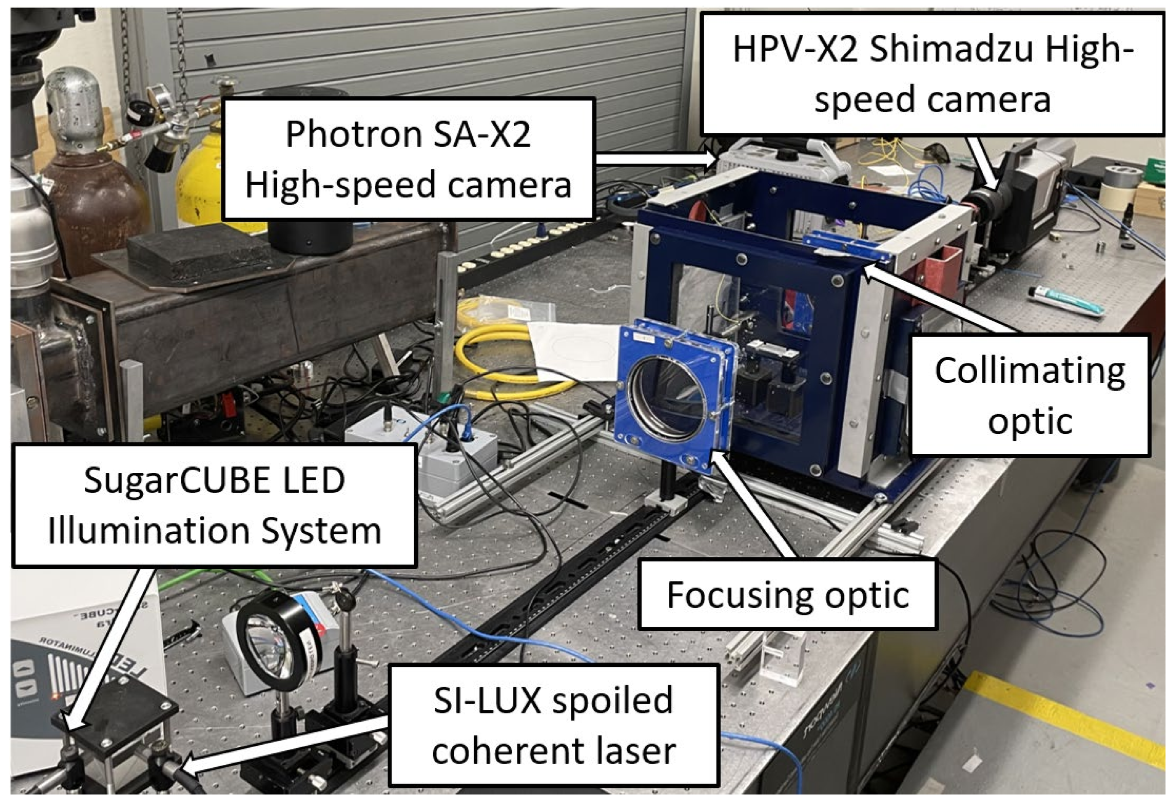

Fig 2: Image of the experimental schlieren imaging system.

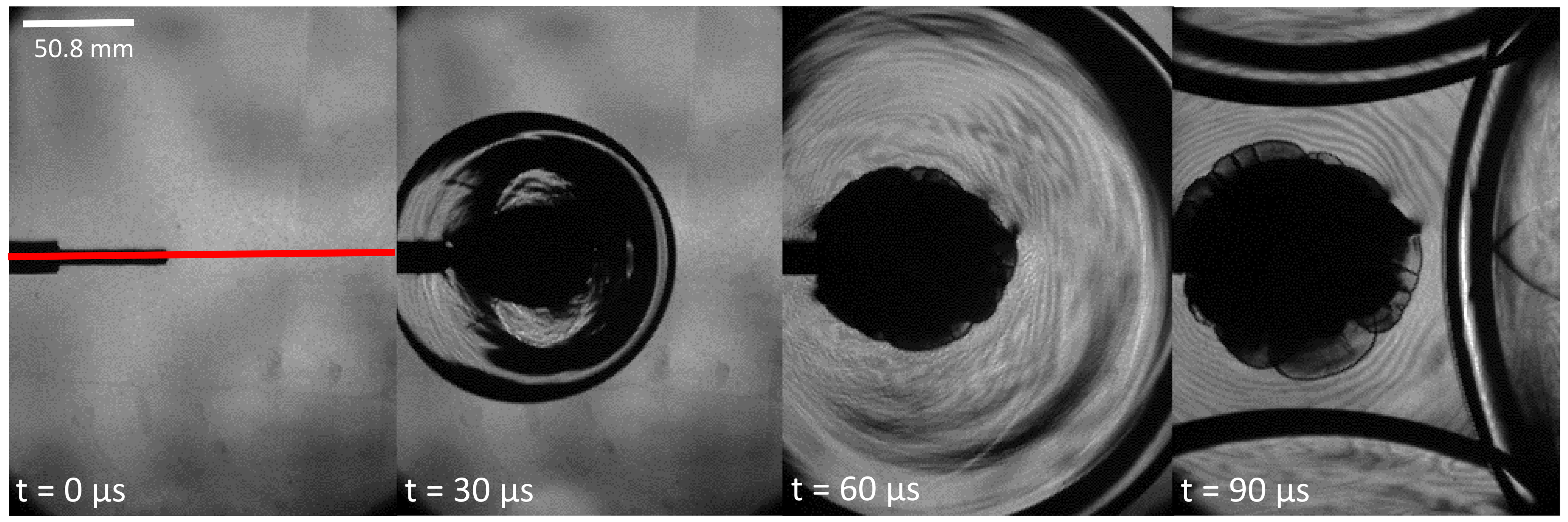

Fig 3: Images of shock wave propagation and fracture growth in a 0.3 m x 0.3 m x 0.3 m PMMA cube. The red line on the starting image indicates the location of the row of pixels extracted for creation of a streak image.

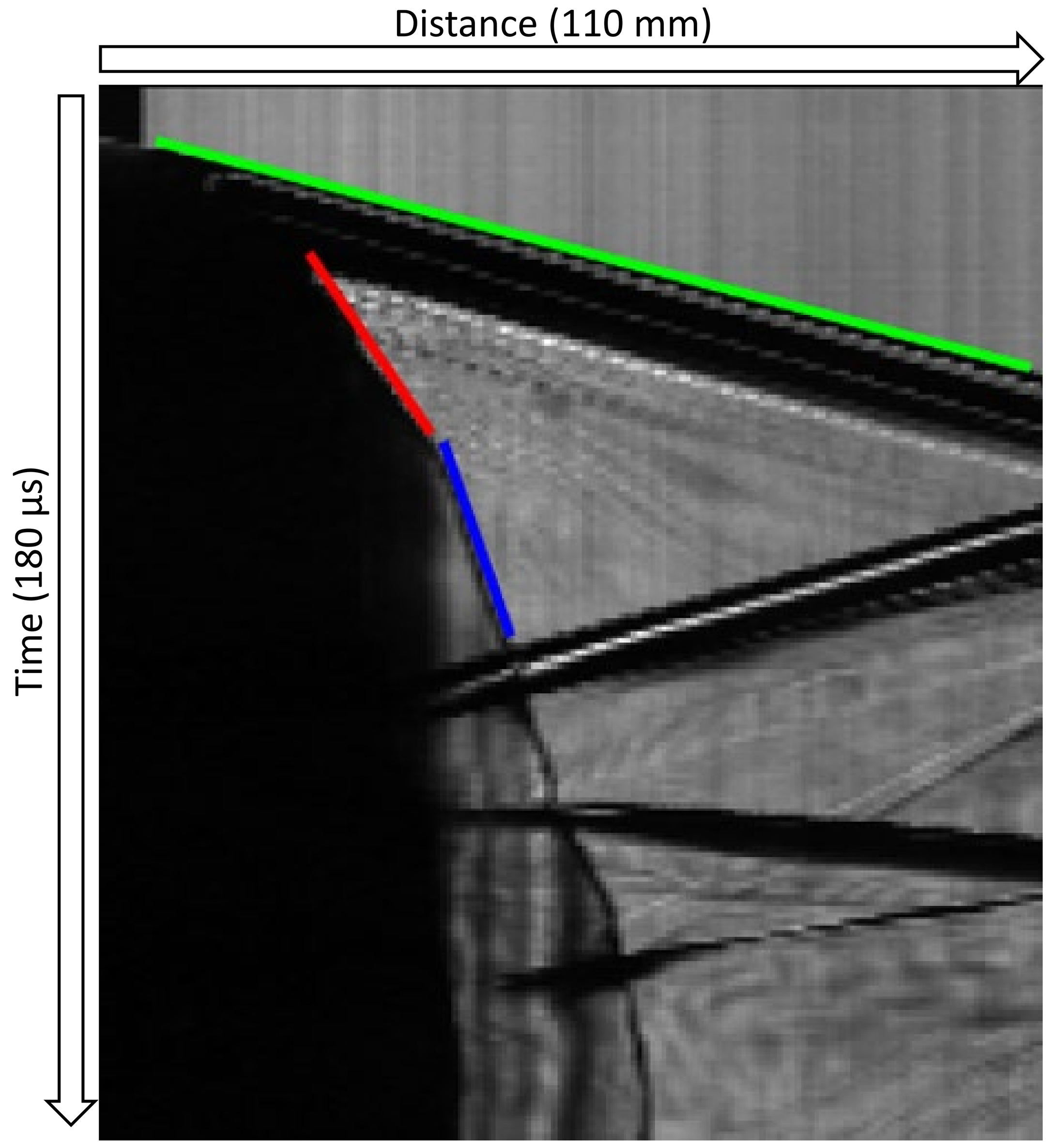

Fig 4: Distance - time image for a 0.3 m x 0.3 m x 0.3 m PMMA cube with the linear fit to the shock (green) and fracture (red and blue) fronts.

The high speed schlieren images are used to create time – distance graphs (streak images). The image is created by extracting a single row of pixels, indicated using the red line in Fig 3, from each image in the data set and stacking them vertically. Fig 4 shows a streak image where the shock front, green line, was extracted and a linear trend line was fit. The inverse of the slope yields a wave velocity of approximately 2800 m/s. The same process was applied to the fracture growth represented by the red and blue lines yielding velocities of 510 m/s and 250 m/s, respectively. The discontinuity in the fracture growth indicates that there is more than one mechanism driving the fracture growth. The fracture behavior investigation begins with understanding how the pressure wave drives fracture growth. This is achieved through implementation of PDV and schlieren imaging close to the explosive source.

PDV of Shock Pulse

PDV is an interferometry technique used to experimentally determine the particle velocity or free surface velocity of an interface. The PDV probe is directed at a diffuse reflector as the free surface moves the reflected light is Doppler shifted [5]. The surface movement is represented as a beat frequency from the Doppler shifted light and a reference laser of a different frequency [5] which are combined, digitized, and recorded using an oscilloscope.

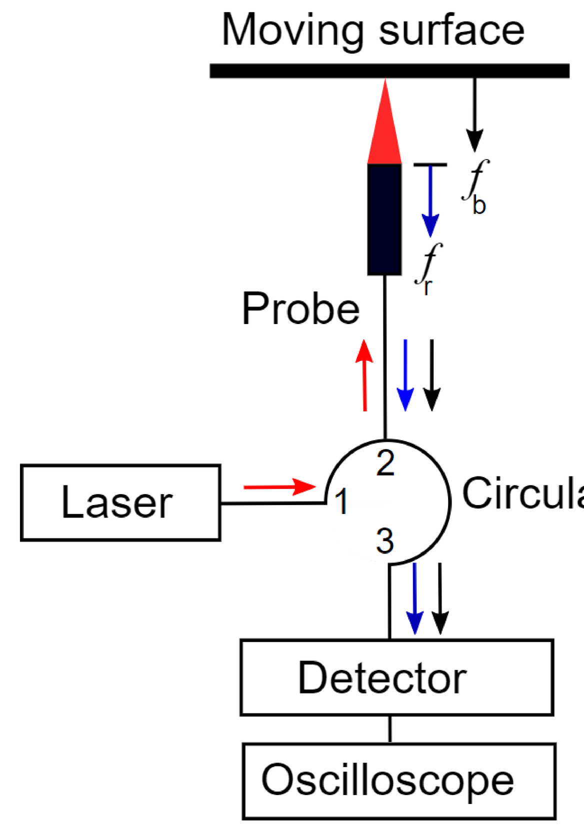

Fig 5: Schematic of the PDV system.

PDV was used to determine the particle velocity history at surface distances 25.4 – 133.3 mm from the explosive source. The recorded beat frequency is converted to a Short-Time Fourier Transform (STFT) spectrum using a program developed by Sandia National Labs [6]. Fig 6a shows the STFT spectrum for a distance of 25.4 mm from the source. The processed frequency signal is converted to particle velocity history shown in Fig 6b. The initial spike in the PDV data represents the particle velocity of the PMMA for the pressure wave.

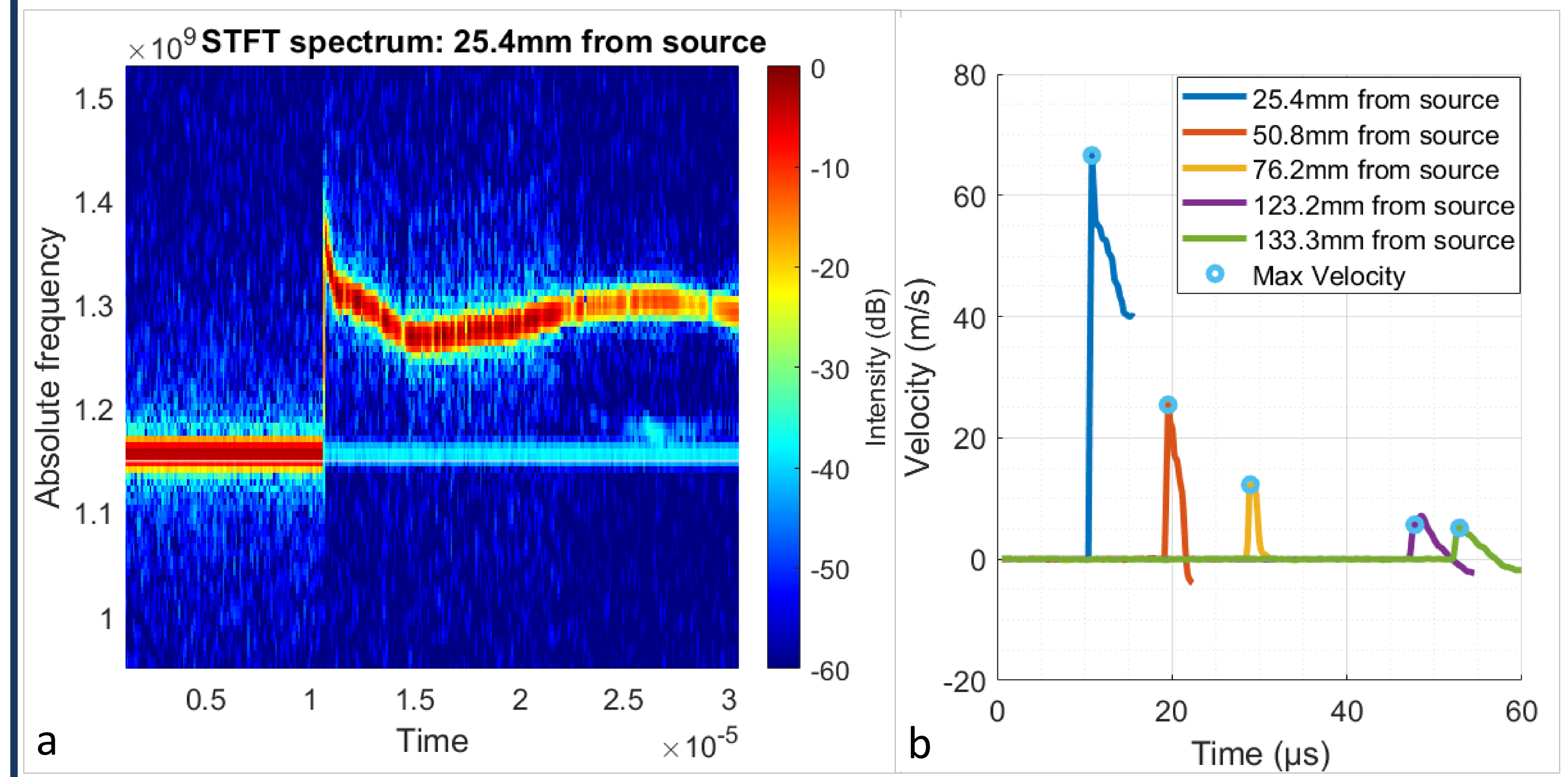

Fig 6: a) STFT spectrum for a wave propagation thickness of 25.4 mm. b) Particle velocity history graph for wave propagation thicknesses of 25.4 mm to 133.3 mm.

Particle velocity is directly proportional to stress, but the conversion is state dependent. The decay behavior of the particle velocity indicates the wave is elastic. The particle velocity was converted to stress through: $\sigma = \rho C_d u_p$ which defines the stress state of the PMMA as the wave propagates 25.4 – 133.3 mm from the explosive source.

Table 1: Summary of the experimentally determined shock velocity and particle velocity along with the calculated stress.

Propagation thickness (mm)	Shock velocity (km/s)	Particle velocity (km/s)	Stress (MPa)
25.4	3.042	0.072	232.5
50.8	2.854	0.0275	88.80
76.2	2.789	0.0133	42.95
123.2	2.770	0.0061	19.50
133.3	--	0.0052	16.79